

CLAIMS

5

1. A flash memory device, characterized by:  
a silicon substrate,  
a first electrode formed on said silicon  
substrate with an insulation film interposed  
10 therebetween, and  
a second electrode formed on said first  
electrode with an inter-electrode insulation film  
interposed therebetween,  
said inter-electrode insulation film having  
15 a stacked structure including at least one silicon  
oxide film and one silicon nitride film, at least a  
part of said silicon oxide film containing Kr with a  
surface density of  $10^{10}\text{cm}^{-2}$  or more.

20

2. A flash memory device as claimed in  
claim 1, characterized in that said first electrode  
25 includes a polysilicon film on a surface thereof, and  
wherein said inter-electrode insulation film has a  
stacked structure in which a first silicon nitride  
film, a first silicon oxide film, a second silicon  
nitride film and a second silicon oxide film are  
30 stacked consecutively.

3. A flash memory device as claimed in claim 1, characterized in that said first electrode includes a polysilicon film on a surface thereof, and wherein said inter-electrode insulation film is  
5 formed of three layers of a silicon oxide film, a silicon nitride film and a silicon oxide film.

10

4. A flash memory device as claimed in claim 1, characterized in that said first electrode includes a polysilicon film on a surface thereof, and wherein said inter-electrode film is formed of two  
15 layers of a first silicon nitride film and a second silicon oxide film.

20

5. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
25 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure including therein at least one silicon oxide film and one  
30 silicon nitride film,

characterized in that said silicon oxide film is formed by a process comprising the steps of: supplying a gas containing oxygen and a gas

predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a microwave.

5

6. A method of fabricating a flash memory device, said flash memory device comprising a silicon  
10 substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode  
15 insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,  
20 characterized in that said first and second silicon oxide films are formed by a process comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said  
25 processing chamber by a microwave.

30 7. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed

therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon oxide film, a silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface, characterized in that said first and second silicon oxide films are formed by a process comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a microwave.

15

8. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said silicon oxide film are formed by a process comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a

30

microwave.

5

9. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
10 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure including at least one silicon oxide film and at least one  
15 silicon nitride film,

characterized in that said silicon oxide film is formed by a process comprising the step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen  $O^*$  formed by microwave  
20 excitation of plasma in a mixed gas of an oxygen-containing gas and an inert gas predominantly of a Kr gas.

25

10. A fabrication process of a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
30 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode

insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said  
5 first electrode having a polysilicon surface,

characterized in that said first and second silicon oxide films are formed by a process comprising the step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen O\*  
10 formed by exciting plasma in a mixed gas of a gas containing oxygen and a gas predominantly of a Kr gas, by a microwave.

15

11. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon  
20 substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a  
25 first silicon oxide film, a silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said second silicon oxide film are formed by a process comprising the  
30 step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen O\* formed by exciting plasma in a mixed gas of a gas containing oxygen and a gas predominantly of a Kr gas by a

microwave.

5

12. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
10 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure including at least one silicon oxide film and at least one  
15 silicon nitride film,

characterized in that said silicon nitride film are formed by a process comprising the steps of: introducing a gas containing any of an  $\text{NH}_3$  gas or an  $\text{N}_2$  gas and an  $\text{H}_2$  gas and a gas predominantly of an Ar  
20 gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

25

13. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
30 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode

insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said  
5 first electrode having a polysilicon surface,

characterized in that said first and second silicon nitride films are formed by a process comprising the steps of: introducing an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$  and a gas predominantly of  
10 an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

15

14. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon  
20 substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a  
25 first silicon oxide film, a silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said silicon oxide film are formed by a process comprising the steps of:  
30 introducing an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$  and a gas predominantly of an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.



15. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
5 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are  
10 stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said silicon nitride film are formed by a process comprising the steps of: introducing an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$   
15 and a gas predominantly of an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

20

16. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon  
25 substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure containing  
30 at least one silicon oxide film and at least one silicon nitride film,

characterized in that said silicon nitride film is formed by a process comprising the step of:

exposing a silicon nitride film deposited by a CVD process to hydrogen nitride radicals  $\text{NH}^*$  formed by microwave excitation of plasma in a mixed gas of an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$  and a gas  
5 predominantly of an Ar gas or a Kr gas.

10 17. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said  
15 first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second  
20 silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that each of said first and second silicon nitride films is formed by a process comprising the step of: exposing a silicon  
25 nitride film deposited by a CVD process to hydrogen nitride radicals  $\text{NH}^*$  formed by exciting plasma in a mixed gas of an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$  and a gas predominantly of an Ar gas or a Kr gas by a microwave.

30

18. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed  
5 therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said first electrode having a polysilicon surface,

characterized in that said silicon nitride  
10 film is formed by a process comprising the step of: exposing a silicon nitride film deposited by a CVD process to hydrogen nitride radicals  $NH^*$  formed by exciting plasma in a mixed gas of an  $NH_3$  gas or a gas containing  $N_2$  and  $H_2$  and a gas predominantly of an Ar  
15 gas or a Kr gas by a microwave.

20 19. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said  
25 first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are stacked consecutively, said first electrode having a  
30 polysilicon surface,

characterized in that said inter-electrode insulation film is formed by a process comprising the step of: exposing a silicon nitride film deposited by

a CVD process to hydrogen nitride radicals  $\text{NH}^*$  formed by exciting plasma in a mixed gas of an  $\text{NH}_3$  gas or a gas containing  $\text{N}_2$  and  $\text{H}_2$  and a gas predominantly of an Ar gas or a Kr gas by a microwave.

5

20. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode of polysilicon formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode oxide film interposed therebetween, characterized in that said inter-electrode oxide film is formed by a process comprising the steps of:

depositing a polysilicon film on said silicon substrate as said first electrode; and exposing a surface of said polysilicon film to atomic state oxygen  $\text{O}^*$  formed by exciting plasma in a mixed gas of a gas containing oxygen and an inert gas predominantly of a Kr gas by a microwave.

25

21. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode of polysilicon formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode

30

formed on said first electrode with an inter-electrode nitride film,

characterized in that

said inter-electrode nitride film is formed by a

5 process comprising the steps of:

depositing a polysilicon film on said silicon substrate as said first electrode; and

10 exposing a surface of said polysilicon film to hydrogen nitride radicals  $NH^*$  formed by exciting plasma in a mixed gas of a gas containing nitrogen and hydrogen and an inert gas predominantly of a Kr gas by a microwave.

15

22. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode of polysilicon formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode oxynitride film interposed therebetween,

20 characterized in that said inter-electrode oxynitride film being formed by a process comprising the steps of:

depositing a polysilicon film on said silicon substrate as said first electrode; and

30 converting a surface of said polysilicon film to a silicon oxynitride film by exposing said polysilicon film to plasma formed by exciting a mixed gas of an inert gas predominantly of Ar or Kr and a gas containing oxygen and nitrogen by a microwave.

23. A method of forming a silicon oxide film, characterized by the steps of:

depositing a polysilicon film on a substrate; and

5           forming a silicon oxide film on a surface of said polysilicon film by exposing the surface of said polysilicon film to atomic state oxygen O\*, said atomic state oxygen O\* being formed by exciting plasma in a mixed gas of a gas containing oxygen and  
10   an inert gas predominantly of a Kr gas by a microwave.

15           24. A method of forming a silicon oxide film as claimed in claim 23, characterized in that said mixed gas is a mixture of oxygen and an inert gas predominantly of a Kr gas with a mixing ratio of 3% for oxygen and 97% for the inert gas.

20

25           25. A method of forming a silicon oxide film as claimed in claim 23, characterized in that said plasma has an electron density of  $10^{12}\text{cm}^{-3}$  or more on said surface of said polysilicon film.

30

26. A method of forming a silicon oxide film as claimed in claim 23, characterized in that

said plasma has a plasma potential of 10 V or less at said surface of said polysilicon film.

5

27. A method of forming a silicon nitride film, characterized by the steps of:

depositing a polysilicon film on a  
10 substrate; and  
forming a nitride film on a surface of said polysilicon film by exposing the surface of said polysilicon film to hydrogen nitride radicals  $NH^*$ , said hydrogen nitride radicals  $NH^*$  being formed by  
15 plasma that is excited in a mixed gas of a gas containing nitrogen and hydrogen as constituent elements and an inert gas predominantly of an Ar gas or a Kr gas by a microwave.

20

28. A method of forming a silicon nitride film as claimed in claim 27, characterized in that  
25 said gas containing nitrogen and hydrogen is an  $NH_3$  gas.

30

29. A method of forming a silicon nitride film as claimed in claim 27, characterized in that said mixed gas is a mixture of an  $NH_3$  gas and an

inert gas predominantly of an Ar gas or a Kr gas with a mixing ration of 2% for said  $\text{NH}_3$  gas and 98% for said inert gas.

5

30. A method of forming a silicon nitride film as claimed in claim 27, characterized in that  
10 said gas containing nitrogen and hydrogen is a mixed gas of an  $\text{N}_2$  gas and an  $\text{H}_2$  gas.

15

31. A method of forming a silicon nitride film as claimed in claim 27, characterized in that  
said plasma has an electron density of  $10^{12}\text{cm}^{-3}$  or  
more at said surface of said polysilicon film.

20

32. A method of forming a silicon nitride  
25 film as claimed in claim 27, characterized in that  
said plasma has a plasma potential of 10 V or less at  
said surface of said polysilicon film.

30

33. A method of forming an oxynitride film,  
characterized by the steps of:



depositing a polysilicon film on a substrate; and

converting a surface of said polysilicon film to a silicon oxynitride film by exposing said  
5 polysilicon film to plasma formed by exciting a mixed gas of an inert gas predominantly of Ar or Kr and a gas containing oxygen as a constituent element and a gas containing nitrogen as a constituent element, by a microwave.

10

34. A method of forming a silicon  
15 oxynitride film as claimed in claim 33, characterized in that said gas containing nitrogen is an  $\text{NH}_3$  gas.

20

35. A method of forming a silicon  
oxynitride film as claimed in claim 33, characterized  
in that said mixed gas is a mixture of an inert gas  
predominantly of Ar or Kr and an oxygen gas and an  
25  $\text{NH}_3$  gas with a mixing ratio of 96.5% for said inert gas and 3% for said oxygen gas and 0.5% for said  $\text{NH}_3$  gas.

30

36. A method of forming a silicon  
oxynitride film as claimed in claim 33, characterized

in that said gas containing nitrogen is a mixed gas of an  $N_2$  gas and an  $H_2$  gas.

5

37. A method of forming a silicon oxynitride film as claimed in claim 33, characterized in that said plasma has an electron density of  $10^{12} \text{cm}^{-3}$  or more at said surface of said polysilicon film.

15

38. A method of forming a silicon oxynitride film as claimed in claim 33, characterized in that said plasma has a plasma potential of 10V or less at said surface of said polysilicon film.

20

39. A method of forming a silicon oxide film on a polysilicon film, characterized by the steps of:

forming plasma containing therein atomic state oxygen  $O^*$  in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a shower plate provided in a part of said processing vessel so as to extend parallel with a substrate to be processed, said shower place including a number of apertures for supplying a

30

plasma gas toward said substrate to be processed, and  
a microwave radiation antenna provided such that said  
microwave radiation antenna emits a microwave into  
said processing vessel through said shower plate,  
5 said plasma being formed by supplying an inert gas  
predominantly of Kr and a gas containing oxygen into  
said processing vessel via said shower plate, and by  
supplying a microwave into said processing vessel  
from said microwave radiation antenna through said  
10 shower plate; and

oxidizing, in said processing vessel, a  
surface of said polysilicon film formed on said  
substrate by said plasma, to form said silicon oxide  
film.

15

40. A method of forming a silicon oxide  
20 film as claimed in claim 39, characterized in that  
said plasma has an electron density of  $10^{12}\text{cm}^{-3}$  or  
more at said surface of said polysilicon film.

25

41. A method of forming a silicon oxide  
film as claimed in claim 39, characterized in that  
said plasma has a plasma potential of 10V or less at  
30 said surface of said polysilicon film.

42. A method of forming a silicon nitride film on a polysilicon film, characterized by the steps of:

forming plasma containing therein hydrogen  
5 nitride radicals  $NH^*$  in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a shower plate provided in a part of said processing vessel so as to extend parallel  
10 with a substrate to be processed, said shower plate including a number of apertures for supplying a plasma gas toward said substrate to be processed, and a microwave radiation antenna provided such that said microwave radiation antenna emits a microwave into  
15 said processing vessel through said shower plate, said plasma being formed by supplying an inert gas predominantly of Ar or Kr and a gas containing nitrogen and hydrogen into said processing vessel via said shower plate, and by supplying a microwave into  
20 said processing vessel from said microwave radiation antenna through said shower plate; and  
nitriding, in said processing vessel, a surface of said polysilicon film formed on said substrate by said plasma, to form said silicon  
25 nitride film.

30 43. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said gas containing nitrogen and hydrogen is an  $NH_3$  gas.

44. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said gas containing nitrogen and hydrogen is a mixed  
5 gas of an  $N_2$  gas and an  $H_2$  gas.

10 45. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said plasma has an electron density of  $10^{12}cm^{-3}$  or more at said surface of said polysilicon film.

15

46. A method of forming a silicon nitride film as claimed in claim 42, characterized in that  
20 said plasma has a plasma potential of 10V or less at said surface of said polysilicon film.

25

47. A method of forming a silicon oxynitride film on a polysilicon film, characterized by the steps of:

forming plasma containing therein atomic  
30 state oxygen  $O^*$  and hydrogen nitride radicals  $NH^*$  in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a

shower plate provided in a part of said processing vessel so as to extend parallel with a substrate to be processed, said shower place including a number of apertures for supplying a plasma gas toward said substrate to be processed, and a microwave radiation antenna provided such that said microwave radiation antenna emits a microwave into said processing vessel through said shower plate, said plasma being formed by supplying an inert gas predominantly of Ar or Kr and a gas containing oxygen as a constituent element and a gas containing nitrogen as a constituent element into said processing vessel via said shower plate, and by supplying a microwave into said processing vessel from said microwave radiation antenna through said shower plate; and

oxynitriding, in said processing vessel, a surface of said polysilicon film formed on said substrate by said plasma, to form said silicon oxynitride film.

20

48. A method of forming a silicon oxynitride film as claimed in claim 47, characterized in that said gas containing nitrogen and hydrogen is an  $\text{NH}_3$  gas.

30

49. A method of forming a silicon

oxynitride film as claimed in claim 47, characterized in that said gas containing nitrogen and hydrogen is a mixed gas of an N<sub>2</sub> gas and an H<sub>2</sub> gas.

5

50. A method of forming a silicon  
oxynitride film as claimed in claim 47, characterized  
10 in that said plasma has an electron density of  $10^{12}\text{cm}^{-3}$   
or more at said surface of said polysilicon film.

15

51. A method of forming a silicon  
oxynitride film as claimed in claim 42, characterized  
in that said plasma has a plasma potential of 10V or  
less at said surface of said polysilicon film.

20